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COMMITTEE ON THE PEACEFUL USES OF OUTER SPACE

SIXTH UNITED NATIONS/WORLD METEOROLOGICAL ORGANIZATION/EUROPEAN
SPACE AGENCY TRAINING COURSE ON THE USE OF VISIBLE, INFRARED AND
MICROWAVE SENSOR SYSTEMS IN HYDROLOGICAL AND AGROMETEOROLOGICAL
APPLICATIONS, ORGANIZED IN COOPERATION WITH THE GOVERNMENT OF
PERU

(Lima, 7-25 October 1991)

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INTRODUCTION

A. Background and objective

1. At its thirty-seventh session, in its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided, among other things, that the United Nations Programme on Space Applications should organize training courses on advanced space science applications and new developments for the benefit of Member States, particularly the developing countries.
2. The United Nations/World Meteorological Organization (WMO)/European Space Agency (ESA) Training Course on the Use of Visible, Infrared and Microwave Sensor Systems in Hydrological and Agrometeorological Applications was one of the activities of Programme on Space Applications for 1991 that were endorsed by the General Assembly in its resolution 45/72 of 11 December 1990. The training course was organized in cooperation with the Government of Peru and hosted by the Comisión Nacional de Investigación y Desarrollo Aeroespacial (CONIDA) at Lima from 7 to 25 October 1991 for the benefit of participants from the Economic Commission for Latin America and the Caribbean (ECLAC) region.
3. The objective of the course was to provide education and practical hands-on training to participants on various aspects of current and future visible, infrared and microwave remote-sensing systems, including the acquisition, processing, interpretation, applications and archiving of the data generated by such systems. Particular emphasis was to be placed on satellite radar systems and on the use of their data in hydrology, agrometeorology, forestry and oceanographic applications.
4. The present report, which covers the background, objective and organization of the course as well as a summary of the lectures presented, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. The participants will report to the appropriate authorities in their respective countries.

B. Organization and programme

5. The participants were professionals with several years of experience in agronomy, meteorology, hydrology, forestry, agrometeorology and remote sensing. The co-sponsors jointly selected 24 participants and 5 observers from the following 14 countries: Argentina, Bolivia, Chile, Colombia, Cuba, Ecuador, Guatemala, Honduras, Mexico, Netherlands Antilles, Panama, Peru, Uruguay and Venezuela. Instruction was provided by experts from Canada, Peru, WMO, ESA and the United Nations (Outer Space Affairs Division).

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6. Funds allocated by the United Nations, WMO and ESA for the organization of the training course were used to defray the cost of international air travel and daily subsistence allowance for 18 participants from the ECLAC region. The Government of Peru, through CONIDA, provided the course's classroom and laboratory facilities, consumable materials and local transportation for all participants.

7. Opening addresses were presented by Mr. Ricardo Coloma, Institutional Head, CONIDA, on behalf of the Government of Peru, by Mr. Jean-Pierre Guignard on behalf of ESA and by Mr. Sergio Camacho on behalf of the United Nations. A statement from Prof. G. O. P. Obasi, Secretary-General of WMO, was also read at the opening ceremony.

I. OVERVIEW OF THE COURSE

A. Introduction and scope of the course

8. There have been accelerated improvements in remote-sensing systems and in the computer hardware and software used to analyse and extract information from the data that is being acquired by these systems. As the new generation of Earth-observing satellites, particularly the radar satellites, are launched and become operational, an increasing amount and diverse type of data is becoming available. Radar satellites will provide data over frequently cloudy areas that could not be monitored in the past. The use of these microwave data along with data obtained in the visible and infrared portions of the electromagnetic (EM) spectrum in Geographic Information Systems (GIS) will become a powerful tool to monitor, manage and protect the natural resources and the environment of the Earth.

9. For a profitable use of such technological resources, it will be necessary to form groups of specialists who understand and can apply these rapidly evolving technologies. The course was designed to provide participants with the knowledge of the physical principles involved in remote sensing in various regions of the EM spectrum, the issues associated with the acquisition and processing of the data and the use of multi-temporal, multi-sensor data in specific applications.

10. Radars used for remote-sensing purposes may be grouped into three different categories: altimeters, scatterometers and imaging radars. Specialized applications use altimeters to determine the altitude of an object, e.g., a satellite, above ground level; their applications are usually to determine land and ocean topography. Scatterometers are used to determine wind speed over a sea surface or as data to assist in the analysis of other radar data. Imaging radar can provide picture-like representations of the observed scene and finds its applications primarily in natural resource surveys and environmental monitoring. The microwave portion of the course focused primarily on imaging radars and on the analysis and interpretation of their data.

B. Fundamentals of remote sensing

11. The development of remote-sensing applications requires a knowledge of the scientific principles underlying remote sensing, including the propagation of electromagnetic radiation through the atmosphere, the interaction of radiation with matter, the detection of radiation by the sensor systems and the generation of images in photographic or computerized form. The sensors themselves are classified as imaging or non-imaging depending on whether the sensor data can be converted into a map-like representation of the scene observed. Remote sensing deals primarily with imaging sensors. Sensor systems are also classified as active or passive systems depending on whether they supply their own source of radiation, as in the case of radar, or use natural radiation, as in the case of photographic systems.

12. Airborne photographic cameras are still commonly used remote-sensing systems. The advantages offered by aerial photography include geometric accuracy, stereoscopic relief information, a broad range of image scale and coverage depending on the flight altitude and camera focal length, a broad choice of film-filter combinations to select spectral bands, well-established procedures for acquiring and interpreting images, a large number of experienced photo-interpreters and photogrammetrists and the flexibility of acquiring images at the desired time and place.

13. Photographic systems are sensitive to the visible portion of the electromagnetic spectrum and to portions of the ultraviolet and near infrared regions. Because shorter wavelength radiation is scattered more by the atmosphere, resulting in hazy images, the ultraviolet band is not commonly used for remote-sensing purposes, and blue light is often excluded in favour of near infrared radiation. Thus, the three commonly used bands in colour photography in remote sensing are the green, red and infrared bands. The selection of photographic spectral bands, through the selection of films and filters, is determined by the spectral characteristics of the objects to be studied. Colour infrared film (with filters to eliminate blue light), for example, is used to study vegetation since green leaves are highly reflective in the near infrared and that reflectance is sensitive to vegetation type and condition.

14. The information obtained from aerial or space photography is generally used to create a map or is transferred onto a map. This can be done either by tracing features from the photograph onto a transparent overlay, by visually comparing features of the photograph with corresponding features on a map and transferring information freehand or by using equipment that optically or digitally superimposes the photographic image on the map.

15. Photo-interpretation involves the identification and evaluation of features on a photograph that are considered significant for some applications. The photographic elements on which the identification and evaluation are based are the size, shape, tone and colour, texture, pattern, shadow, site and association of the various features on the photograph.

16. Visual interpretation of satellite imagery is an extension of photo-interpretation of aerial photography, differing mainly in that the large scale of the satellite imagery and the lack of stereoscopy (except in the case of some SPOT data) make features less easily recognizable. While an untrained viewer can recognize many common features such as trees, rows of crops, buildings, roads and animals, on a small-scale aerial photograph these features are generally too small to be seen on satellite imagery, and few untrained viewers can reliably interpret the larger features. Information must often be deduced from seemingly abstract textures, patterns and associations. Satellite image interpretation, therefore, tends to be more theoretical and more specialized than photo-interpretation. The repetitive nature of satellite data is often useful in interpretation since images from different seasons or years will show changes that indicate the nature of the area.

17. The information gathered by a sensor system in each of possibly many spectral bands can be converted digitally into an image form. The image can then be represented in black and white with varying grey tones or in colour with varying colour hues. For each band the intensity of tone or hue is proportional to the amount of radiation that was reflected, emitted or back-scattered by an object (target) on the surface being observed. When the primary colours (blue, green or red) are assigned arbitrarily to each spectral band and two or three of the bands are superimposed, the resulting composite image will contain a wide range of colours where each colour is the visual effect of superimposing the primary colour hues corresponding to an object on the ground. Knowing the spectral properties of various targets (e.g. water, vegetation, soil) in the spectral bands in which the sensor system gathered the information, the primary colour that was assigned to each band and the theory of colour, the user would be able, qualitatively, to make a first level identification of most of the objects that appear in the image. For many applications this accuracy and level of classification is sufficient.

18. Since the tones of grey or the digital values that represent an image are a measure of the radiation received by the sensor, a user can perform either a qualitative or a quantitative radiometric analysis or perhaps both. For accurate image analysis and interpretation it is essential that the user have a thorough understanding of the physical processes involved in the creation of an image. This implies being familiar with the two basic principles of radiometry, which are: (a) the validity of the principle of superposition for wavelike phenomena; and (b) the linearity of sensor response to radiation coming in its band of operation.

19. One of the limiting factors in using remote sensing on an operational basis has been the lack of data in time periods that are most adequate for optimal discrimination of features particular to a specific application. Because of cloudy conditions, a multi-temporal approach to land use also suffers from limitations of data availability. To some extent the off-nadir viewing capability of SPOT and the combined use of its data with Landsat's Thematic Mapper data have alleviated these limitations. However, in tropical areas which have excessive cloud cover, the capability of microwave radiation

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to penetrate clouds and light rain showers could make radar imagery of particular value to developing countries.

20. Microwave remote sensing provides the capability for day or night observations and under clear sky or cloudy conditions. This is possible because most microwave sensor systems provide their own source of radiation (i.e., independent of the sun) and because microwave radiation, which is in the 0.3 GHz to 300 GHz (in terms of wavelength, in 1m to 1mm) portion of the EM spectrum, can penetrate through clouds and light rainfall.

21. Although radar systems are usually defined by the frequency interval in which they operate, they are sometimes designated by their wavelength of operation. This is done because newcomers to radar technology are usually more familiar with the concept of wavelength of the EM radiation. However, frequency is the more fundamental property of EM radiation since its frequency remains constant when it passes through media of different densities while its wavelength and velocity change. To transmit information, a carrier wave of a particular frequency can be modulated by varying the amplitude of the wave (AM modulation). An alternative way is to modulate the frequency (FM modulation); this method is less subject to interference and is the one commonly used to transmit high-quality signals.

22. Microwave sensors can be classified into passive and active systems. Passive systems measure microwave radiation emitted by the ground features or by the sun and reflected by the surface. Active systems "illuminate" the area under observation and measure the strength, phase and time delay of the radiation reflected by the ground features.

23. The interaction of microwave radiation with objects on the surface of the Earth depends strongly upon the electrical properties of the objects and the surface roughness relative to the wavelength of the incident radiation. The electrical properties of matter are determined by its dielectric coefficient, which is highly sensitive to water content. An analysis of the returned signal can therefore provide information on the nature of the objects, their relative size, distribution and moisture content.

24. Radar images can be obtained from either an aircraft or a satellite. In both cases, the images are obtained by transmitting microwave pulses at an angle to the vertical and measuring the intensity and time delay of each return pulse. The first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general this pulse corresponds to the object closest to the flight path. Because of the geometry between the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground-point projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected with reference to a digital terrain map.

25. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include a speckle effect, which appears as noise on the image and is related to the frequency coherence of the system, as well as several effects due to the motion of an object with respect either to the sensor system or to other objects in the field of view of the radar.

26. Because the difference in distance between objects directly beneath an aircraft or a satellite is very small, the corresponding return signals often cannot be electronically discriminated. For this reason airborne radars have been designed to scan objects at some distance to one of the sides of the aircraft and are called side-looking airborne radars (SLAR).

27. The spatial resolution attainable from a radar system is independent of the altitude of the sensor platform and increases with the length of the antenna that transmits and receives the microwave pulses. A technique known as Synthetic Aperture Radar (SAR) which applies a linear frequency modulation to a transmitted long pulse in order to simulate a train of short pulses has been developed in order to keep satellite antennas reasonably small. The technique uses the Doppler shift of the reflected pulse due to the motion of the platform and a modified data processing to simulate a much longer antenna. The result is a higher resolution which is only limited by the power that the antenna is capable of transmitting.

28. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter and is determined by a specific range of frequencies, as follows:

<u>Band name</u>	<u>Band limits (GHz)</u>	<u>Band name</u>	<u>Band limits (GHz)</u>
P-band	0.225-0.390	K-band	10.90-36.00
L-band	0.390-1.550	Q-band	36.00-46.00
S-band	1.550-4.200	V-band	46.00-56.00
C-band	4.200-5.750	W-band	56.00-100.0
X-band	5.750-10.90		

For airborne radar missions, which account for the bulk of the microwave data gathered worldwide to date, the most used bands have been the X-band, L-band and the K-band. For the satellite radar systems of the 1990s, the predominant frequency will be the C-band.

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C. Radar concepts

29. For most imaging radar systems, the geometric configuration is such that a microwave beam is radiated from the side of the platform, at an angle to the surface and perpendicular to the flight direction. The radar beam is wide in the vertical dimension and narrow in the horizontal dimension. A two-dimensional imaging plane is produced by the motion of the radar platform which periodically transmits pulses. Thus, continuous strips of the Earth's surface may be "viewed" parallel and oblique to the flight direction. The scanning concept of the imaging radar is, therefore, quite different from that used by scanners that operate in the visible and infrared regions of the EM spectrum. The latter build an image on a line-by-line basis, their viewing geometry is downward looking and the spatial resolution of the images depends on the angular resolution of the sensor system and platform altitude and degrades away from the nadir track.

30. Imaging radars do not depend on angular resolution; instead, their across-track resolution range is determined by measuring the time delays between the reflected signals due to the transmitted pulses. The range resolution depends upon the length of the radiated pulse which determines the distance by which two objects must be separated in order to be discriminated. This resolution increases as the radiated pulses become shorter. The azimuth along-track resolution is determined by the width of the microwave beam which is in turn determined by the length of the antenna. The azimuth resolution increases with the length of the antenna.

31. For SAR instruments, the limiting factor for their range resolution is shortening the transmitted pulse while maintaining sufficient power to detect the reflected signal. This is accomplished by coding the transmitted pulse through a linear frequency modulation, the so-called "chirped pulse". The range components of the return signal must be processed to obtain the corresponding resolution. Azimuth-related components of the same signal must similarly be processed to obtain the along-track resolution. Thus, the acquisition of SAR imagery requires a processing system that can operate on a two-dimensional array of signal data.

Instrumentation

32. A basic imaging radar system consists of a transmitter, a receiver, an antenna designed to transmit and receive microwave energy and a data-processing and recording unit. The transmitter generates a short microwave pulse with a duration of microseconds. This signal is transmitted by the antenna. The antenna directs a narrow beam into the range direction and receives the returned energy portion of this pulse. The design and form of the antenna determine the beam width and swath width of the "illuminated" ground surface.

33. The receiver measures the strength of the returned portion of the transmitted signal and relates the receiving time to the transmitting time in order to determine the range distance of the reflecting object relative to the

radar. The receiver converts the signal waveform from a frequency band suitable for radiation to an equivalent one that is suitable for recording. This requires a correlation process between the transmitter and the receiver. The recorder and processor units turn the raw data either into an optical record (e.g., on film) or into a digital record using high density digital tapes (HDDTs). Further processing of the radar return signals is necessary by means of correlating signal film or HDDT data to produce radar imagery or computer-compatible tapes respectively. The latter may then be used for digital display, image manipulation and analysis.

Microwave polarization

34. An electromagnetic wave consists of coupled electric and magnetic fields which oscillate at right angles to each other in a regular wavelike manner. The polarization of a waveform describes the orientation of the electric field sector at a given point in space during one period of oscillation. In the simplest case, each field oscillates only in one plane: the wave is plane polarized. When the electric field oscillates in a vertical (horizontal) plane, the wave is vertically (horizontally) polarized. Most imaging radars use an antenna that transmits horizontally polarized radiation. Upon incidence on a ground object, a portion of the returned energy retains the same polarization as the transmitted pulse while the remainder of this energy is randomly polarized (i.e., depolarized).

35. Sophisticated radar systems can transmit horizontally and vertically polarized energy. A switching mechanism in the antenna allows it to receive both the horizontal and vertical components of the return signal. Designations such as "HH" and "VV" stand for "horizontal transmit and horizontal receive" and "vertical transmit and vertical receive" respectively. Similarly, "HV" represents "horizontal transmit and vertical receive"; this is known as cross-polarized return. Polarization of the incident radiation is an important discriminating element since ground surfaces and other targets reflect differently each of the two components mentioned. For example, a simplified model of a vegetation canopy composed of vertically linear leaves (scatterers) would provide a strong reflected signal for vertically polarized incoming radiation but a very weak signal if the radiation were polarized horizontally. Thus, the return signal can provide information on the structure of the objects being viewed.

D. Sources of radar data for remote sensing

36. Launched in July 1991, ERS-1 is a low-orbit Earth observation satellite with several microwave sensors on board. The primary mission of ERS-1 is to increase the understanding of ocean processes, to monitor the polar regions and to contribute to the World Climatology Research Programme. However, an increasing number of land-oriented applications will soon result as the international research community attains access to the data. The primary instrument on board ERS-1 is the Active Microwave Instrument (AMI), which can provide high-resolution images (C-band), wind speed through ocean wave spectra

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analyses and the length and direction of ocean waves. Operating in the imaging mode, AMI covers a swath of 80 to 100 kilometres, with initially assessed resolutions of 27 metres in range and 29 metres in azimuth. Preliminary assessment through October 1991 also shows high precision and replicability of the data acquired by ERS-1.

37. Operating in the wind mode, AMI covers a swath of 400-500 km over the ocean with resolution cells of 50 km and measures wind speed in the range of 4 to 24 m/s with an accuracy of 0.5 to 2 m/s. Wind speed and direction are determined by measuring the strength of the back-scattered signal of each resolution element from three directions: obliquely ahead, to the side and obliquely behind the satellite path. The intensity of the three signals provides the wind speed, and the differences between them indicate the wind direction with an accuracy of 20°. In wave mode operation, AMI determines the length and direction of ocean waves in 5 x 5 km cells for segments of 200-300 km along the satellite path. Ocean wavelengths of 100-1,000 m can be measured to an accuracy of 25 per cent and their direction to an accuracy of 20°.

38. In addition to AMI, ERS-1 carries a Radar Altimeter (RA) that operates at a wavelength of 2 cm. This altimeter looks vertically downward to measure average wave height and wind speed and to determine the meso-scale ocean topography. Data from this altimeter will be used to determine ice type and topography as well as the water/ice boundaries. ERS-1 also carries an Along Track Scanning Radiometer (ATSR) that operates in three bands in the thermal infrared region; these bands are centred around 3.7, 11 and 12 micrometres. ATSR looks through the atmosphere at the surface of the ocean from two directions, downward vertically and at an incidence angle of 50°. The difference between the oblique and vertical measurements provides information on atmospheric absorption while the differences between measurements at the three wavelengths are used to determine atmospheric water vapour content.

39. ERS-1 data is received by ESA's network of ground stations, which include Maspalomas, Spain; Kiruna, Sweden; Fucino, Italy; and Gatineau and Prince Albert, Canada; as well as by a number of ground stations located in the industrialized and developing countries. User requests for acquisition of ERS-1 data over a particular area of the Earth or requests for specific products of ERS-1 data already acquired are channelled through ESA's Earthnet Central Facility (EECF) located in Frascati, Italy. The EECF supports the cataloguing and archiving of ERS-1 data acquired and provides a browse option that is available to the users.

40. To date, most of the radar data collected worldwide have been obtained by airborne radar systems. Even with the arrival of radar satellite systems, aerial systems will continue to provide data to meet specific user-determined acquisition parameters, particularly flight direction, viewing angle and high spatial resolution. The C/X-SAR sensor was planned and integrated on board its Convair 580 aeroplane by the Canada Centre for Remote Sensing (CCRS). This system was designed and built by MacDonald-Dettwiler Ltd. and Canadian Astronautics Ltd., to operate in the C- and X-bands for use by the research

and development community. This SAR sensor is capable of imaging the Earth's surface in three modes: nadir, narrow and wide swath. At its optimum operating altitude of 6 km, the C/X-SAR sensor can provide a ground resolution of 6 m x 6 m over depression angles from 16° to 90° (nadir mode) or 14° to 45° (narrow swath). The nadir mode is useful in terrain of high relief or for simulation of satellite SAR geometry.

41. Although the bulk of the satellite radar data that will be acquired over at least the next 10 years will be obtained in the C-band, most of the experience developed to date has been with radar operating in the X-, L- and K-bands. Airborne radar such as the C/X-SAR can also be used to investigate the use of C-band radar in monitoring the Earth.

42. A project aimed at studying the use of C-band data over moist tropical forests and their environs was proposed by Canada during the First Space Conference of the Americas, held at San José, Costa Rica, during 1990. As a result, a SAR data acquisition mission for this purpose has been organized and is under way under the auspices of ESA. In 1992, the mission will acquire C-band data over a number of Latin American countries using the CCRS Convair 580 aircraft. The main objectives of this regional cooperation project are to determine the ability of C-band SAR data to detect and map forest cover types, clearings, burned areas and forest regeneration, extent of flooding, agriculture distribution, natural dams and rivers caused by rock slides and landslides and various other types of surface changes. The project will document the results of these investigations to promote the knowledge of radar among professionals and technical staff responsible for management of natural resources and the environment in the region.

43. Airborne radar data have also been collected over various regions around the world, including Peru and other regions of Latin America, by two other SAR instruments operated on a commercial basis by Intera Kenting, Canada. The STAR-1 (Sea-Ice and Terrain Assessment Radar) system, developed in 1983, and the STAR-2 system, developed in 1987, are fully focused X-band Synthetic Aperture Radars with real-time processors on board the aircraft. The characteristics of both instruments are similar, with the major performance difference being in their range resolution. STAR-1 can provide a maximum ground resolution of 6 m x 6 m while STAR-2 provides a 5.4 m x 4.0 m resolution when operated in narrow swath mode. In this mode and flying an altitude of 7.0 km, the STAR systems view a swath width of 18 km and adjacent flight lines produce an overlap of 10 km strips; this permits stereo reconstruction of the terrain. In the absence of ground control points, the aircraft use navigational information and an on board Global Positioning Systems (GPS) to relate aircraft coordinates to image coordinates. Topographic mapping products at scales of up to 1:50,000 can then be created utilizing algorithms that enable the radar image pixels to be geocoded.

44. Data from STAR-1 and STAR-2 have been used in commercial applications to mineral and petroleum exploration. Radar data have been used to create Digital Elevation Models (DEMs) of the terrain and orthorectified radar images with elevation contours overlaid on them at a 1:50,000 scale. For regions

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with little or no cartography these products can be used as planimetrically accurate base maps, topographic representations and as source data for thematic (geological) interpretation. In particular, these products can be used by planning teams and field crews for laying out seismic lines in the foothills, by helicopter-borne teams performing geological field sampling and by geophysicists who use DEMs for interpretation purposes. The geological information that can be extracted from radar images includes terrain relief, regional lineaments, joints, fractures, folding, anticlinal and synclinal structure and drainage patterns.

45. Other SAR data, obtained by the SEASAT satellite (1978), the Shuttle Imaging Radar-B (SIR-B) and Aircraft SAR (AIRSAR) mission of the United States are kept in the archives of the Radar Digital Processing Group at the Jet Propulsion Laboratory (JPL) at Oak Grove, California. Information on the characteristics of the missions and on the data obtained by them can be accessed through JPL's SAR Data Catalogue System (SDCS), from a remote terminal. The SDCS also contains an on-line inventory of digital terrain data that is kept in the archives at JPL.

E. Digital image processing and analysis

46. The capability to digitally process large volumes of data with uniform criteria, and often data that have been enhanced or which include new bands as a result of linear transformations of the original ones, allows the routine monitoring of large areas and the attainment of a finer discrimination between classes in the scene.

47. Satellite image data as provided to the users does not generally represent the surface of the Earth with the geometric fidelity necessary for topographic maps and does not usually fit into existing standard map projections. This is due to effects that are introduced by changes in attitude, altitude and spacecraft velocity, non-linearities in the sensor scan process, unequal sensor response, effects of the Earth's curvature and rotation and elevation of the satellite over the Earth's surface. Most of these effects (the systematic ones) can be compensated for during the preprocessing geometric and radiometric correction stage; this is done more efficiently using a digital process.

48. Digital image enhancement improves the visual presentation of the information content of the image. These techniques assist in a visual interpretation or in reducing the amount of digital data to be processed but do not create any new or additional information. Common techniques include the following: contrast enhancement, spatial filtering, linear band combinations and principal component transformations. Since in any image the full dynamic range of values that the pixels could take (typically from 0 to 255) is not utilized, the contrast of the entire image can be digitally improved. A typical range of values in an image is of the order of 80 so that the contrast can be improved visually by a factor of 3. Low-pass and high-pass filters are used to smoothe out the local variations of radiance

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values or to enhance reflectance differences, particularly at borders between two classes of objects. Principal component transformations are a way of reducing the number of data of a set of images while retaining the most significant information. Linear band combinations include generating a new band from the ratio of two bands or the ratio of the difference of two bands to the sum of the same bands; these transformations, and many others that might be performed, enhance features of interest to the interpreter.

49. The final output of the evaluation of remote-sensing data is a thematic image (or map) of the scene analysed depending on the specific interest of the interpreter. The process of achieving this through digital processing is called "classification". Two different approaches to digital image classification have been developed: supervised and unsupervised classification. The first approach requires that the interpreter identify areas representative of the classes to be included in the thematic output in order that the classification algorithm may use statistical parameters to classify each pixel in the image into one of the classes requested. Unsupervised classifiers require little interaction by the user and are based entirely on statistical methods. The rationale behind the latter approach was to make the classifications independent of the skill of the user. However experience has shown that the quality of the supervised classification is usually better since the experience accumulated by the user is more fully utilized.

F. Remote-sensing applications

50. In hydrology, the most useful applications of remote sensing are in locating and conducting inventories of water resources, determining land cover and assessing wetland areas. Various rainfall run-off models currently used for hydrologic modelling were developed before the advent of remote sensing and are based on the use of topographic maps. The use of Digital Terrain Models and topographic images that can be constructed based on data from SPOT and from various radar systems would improve estimates of the amounts and spatial distribution of rainfall losses, particularly over regions where conventionally obtained topographic maps are not available.

51. Other key parameters that need to be determined for hydrologic modelling are: (a) soil moisture, (b) evaporation, (c) land cover, (d) impervious surface area, (e) extent of snow cover and the water equivalent of snow and (f) precipitation. Of these parameters, soil moisture, precipitation and evaporation are the most difficult to obtain. However, the use of remote-sensing data obtained in the visible, infrared and radar portions of the electromagnetic spectrum now permits accurate estimates to be determined for the values of these parameters, although not yet on an operational basis.

52. Meteorology is an area in which there has been a marked improvement in the accuracy of estimating the key parameters. Meteorological parameters are not only important for weather forecasting and atmospheric modelling but are also of great value in hydrology and agrometeorology. A number of techniques

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have been developed to estimate rainfall occurrence and intensity based on satellite data obtained in the visible and thermal infrared (TIR). These techniques are based on observational evidence that shows a correlation between the brightness of cloud tops as seen in visible and infrared images and rainfall. Bright cloud tops as seen in the visible range produce more rainfall than darker clouds. Bright clouds in the visible with colder tops (TIR information) and which are expanding in areal coverage produce more rainfall. Most of the rain occurs in the upwind portion of a growing cloud system where higher clouds with colder tops form in the region of most vigorous convection. The growth of a thunderstorm system and the direction of movement of the clouds are determined from half-hourly meteorological satellite images. Thus, these interpretation techniques are fully operational.

53. Soil moisture can be defined as the temporary storage of precipitation within a shallow layer of the Earth that is generally limited to the zone of aeration or root zone. Although the amount of water in this layer is insignificant when compared to the total amount of water available on a global scale, it is this layer that controls the success of agriculture. However, in spite of its importance, soil moisture is seldom used in the prediction and monitoring of crop productivity because of the difficulty in its determination. Soil moisture is difficult to measure by any means, in a way that is representative of large areas; such measurements are valid only at the place where they are obtained. For agricultural applications, determinations of temporal and spatial differences of soil moisture may be more important than the actual absolute value of soil moisture.

54. Soil moisture is one of the parameters of importance to agriculture which are currently the subject of SAR research. Other key soil parameters where radar could provide valuable information are its roughness and the tillage direction. SAR research is also being conducted on determining the parameters of a plant canopy. These canopy parameters include plant height and density, canopy structure and plant row direction, growth stage, leaf area index and plant biomass and its water content.

55. Along with LANDSAT, SPOT and AVHRR (Advanced Very High Resolution Radiometer) data, satellite SARs are potentially a very useful source of data for crop information systems. Together, these sensor systems span the EM spectrum from the visible and near infrared through the thermal infrared and the microwave regions. The new challenge will be to integrate the data, with different spatial and temporal resolutions, into a complementary system that can provide the continuous information necessary to monitor crop development and to do so in an operational manner.

G. Geographic Information Systems

56. The information derived from each of the various remote-sensing systems is in most cases used for a specific application. Beyond that application, the derived data can be considered raw information that can be used with other information in a Geographic Information System (GIS) for management and policy-making decisions. The sources of data for a GIS are the following:

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remotely sensed data, point measurements such as field-obtained data, existing cartography and statistical or census-type information. The important characteristic of a GIS is that all the data contained in it have positional references, usually geo-coded to corresponding points on the Earth's surface.

57. A GIS can be defined as consisting of the following three basic elements: (a) a large amount of data which have spatial or locational characteristics; (b) an integrated set of programs which distinguishes the GIS from a series of unrelated individual programs; and (c) a common set of sub-components which perform such operations as data storage, retrieval, analysis and display. From a user's point of view a GIS is a relational type of database, spatially indexed in such a way that new information can be added from external sources or created from existing information.

58. A GIS is visualized as consisting of a number of layers, each of which contains thematic information on one or more variables over the surface area being considered. Through user-defined queries, the system can superimpose all or a subset of the layers to produce an output in the form of a tabular or statistical report or as an image either on a television monitor from which a hard copy could be made or in digital form on magnetic tape to be used to generate a map-like product. An example of a final product of a GIS query might be an image display showing the location and areal extent of three soil types in areas with slopes of less than 10° that receive an annual rainfall of at least 400 mm during a six-month period and are less than 50 km from population centres of at least 50,000 inhabitants.

59. A GIS product such as the one indicated above could be used for planning purposes as, for example, in identifying new agricultural areas for particular types of crops and to locate distribution points for the types of fertilizer that would be required. Another important use for GIS products is the use of their products as information for predictive models. While these models would not indicate actual future conditions, they would be capable of indicating the conditions that might be expected if a particular trend (e.g., land degradation) continued at the current rate, or if particular climatic conditions occur (e.g., drought/flooding associated with the El Niño phenomenon). If the appropriate information is input into its database, a GIS can be used to evaluate or predict complex scenarios involving many parameters in a fast and reliable manner. A GIS could be the basis for specialized information systems such as an agricultural information system, a forestry resources information system or an environmental impact information system.

II. EVALUATION OF THE COURSE

60. At the conclusion of the course, the participants were asked to complete a questionnaire regarding various aspects of the organization of the course, the time allotted to the topics and practical exercises as well as the relevance of the course to their current and future activities in their respective agencies. This exercise was followed by a round-table discussion, including both participants and instructors, on the accomplishments of the course and recommendations for future courses.

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61. An analysis of the completed questionnaires shows that the participants were of the opinion that the organization, planning and delivery of the presentations of the course were of high quality. Approximately 50 per cent of the participants felt that more time should have been allotted to practical exercises in digital image processing. Depending on their field of expertise, some participants felt that more time should have been allotted to that applications area. The majority of the participants indicated that the level and content of the training course were appropriate for the specific needs of their work. They were unanimous in expressing their appreciation to the Government of Peru and to the United Nations, the World Meteorological Organization and the European Space Agency for having organized and sponsored the course and expressed their desire for additional training in the use of radar remote sensing.

Annex

PROGRAMME OF THE COURSE

<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
Monday, 7 October	9-9.30 a.m.	Registration	
	9.30-10 a.m.	Opening ceremony	
		<u>Welcome address</u>	
		United Nations	S. Camacho
		World Meteorological Organization	G. O. P. Obasi*
		European Space Agency	J. P. Guignard
		Peru	R. Coloma
	10-10.45 a.m.	Keynote address: Remote sensing in resource management and environment protection	R. Coloma CONIDA
	11 a.m.- 12.30 p.m.	Overview of remote sensing	S. Camacho United Nations
	2-5 p.m.	Fundamentals of electromagnetic radiometry	S. Camacho United Nations
Tuesday 8 October	9-10.30 a.m.	Characteristics of satellite Earth-observation systems	J. P. Guignard ESA
	10.45 a.m.- 12.15 p.m.	Characteristics of meteorological satellite systems (geostationary and polar)	J. P. Guignard ESA
	2-3.30 p.m.	Principles of image formation (data acquisition, digital/analog representation, display techniques)	F. Quispe CONIDA
	3.45-5 p.m.	Spectral, spatial and temporal image resolutions	R. Coloma CONIDA

* A statement from Prof. G. O. P. Obasi, Secretary-General of WMO, was read at the opening ceremony.

<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
Wednesday 9 October	9 a.m.- 12.15 p.m.	ERS-1 microwave sensors from a mission viewpoint	J. P. Guignard ESA
		Orbits and instrument characteristics	
	2-5 p.m.	SAR principles; radar data processing and ERS-1 products	J. P. Guignard ESA
Thursday 10 October	9 a.m.- 12.15 p.m.	ERS-1 results: two months into operation	J. P. Guignard ESA
	2-5 p.m.	Applications of current ERS-1 data	J. P. Guignard ESA
		Discussion on using ERS-1 products	
Friday 11 October	9-10 a.m.	Use of the RESORS information system	R. Coloma CONIDA
	10 a.m.- 12.15 p.m.	Recognizing and evaluating soil erosion and degradation	V. Barrena Univ. Agraria
	2-5 p.m.	Case-study related to the morning session	V. Barrena Univ. Agraria
Monday 14 October	9-10.30 a.m.	Digital image formation and diagnostics	T. Alföldi CCRS
	10.45 a.m.- 12.15 p.m.	Digital image preprocessing and corrections	T. Alföldi CCRS
	2-5 p.m.	Visit to the facilities of Oficina Nacional de Evaluación de Recursos Naturales (ONERN)	Z. Rodriguez ONERN
Tuesday 15 October	9 a.m.- 12.15 p.m.	Principles of digital image analysis - enhancement and classification	T. Alföldi CCRS
	2-5 p.m.	Practical exercises on digital images	T. Alföldi CCRS
Wednesday 16 October	9-10.30 a.m.	Principles and development of radar	J. Sutton Intera Kenting
	10.45 a.m.- 12.15 p.m.	Characteristics of Synthetic Aperture Radar-imaging geometry	T. Alföldi CCRS

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<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
7	2-3.30 p.m.	Target parameters and radar systems	J. Sutton Intera Kenting
	3.45-5 p.m.	Radar image characteristics	J. Sutton Intera Kenting
Thursday 17 October	9 a.m.- 12.15 p.m.	Radar applications in geology and oceanography	J. Sutton Intera Kenting
	2-3.30 p.m.	Radar applications in hydrology	T. Alföldi CCRS
	3.45-5 p.m.	Practical exercises on radar data applications to geology	J. Sutton Intera Kenting
Friday 18 October	9-10.30 a.m.	Radar applications to agriculture	J. Sutton Intera Kenting
	10.45 a.m.- 12.15 p.m.	Radar applications to forestry	T. Alföldi CCRS
	2-3.30 p.m.	Practical exercises on radar applications to forestry	T. Alföldi CCRS
	3.45-5 p.m.	Overview of radar systems and applications	T. Alföldi J. Sutton
Monday 21 October	9-10.30 a.m.	Estimation of rainfall and run-off	N. Ferreira INPE/WMO
	10.45 a.m.- 12.15 p.m.	Applications of remote sensing to agrometeorology	N. Ferreira INPE/WMO
	2-5 p.m.	Practical exercises related to the morning session	N. Ferreira INPE/WMO
Tuesday 22 October	9-9.45 a.m.	Principles of Geographic Information Systems (GIS)	S. Camacho United Nations
	9.45 a.m.- 12.15 p.m.	Structure of a GIS	V. Barrena Univ. Agraria
	2-5 p.m.	Input of satellite, cartographic and tabular data into a GIS	V. Barrena Univ. Agraria

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<u>Date</u>	<u>Time</u>	<u>Subject</u>	<u>Speaker</u>
Wednesday 23 October	9-10.30 a.m.	Products derivable from a GIS analysis	V. Barrena Univ. Agraria
	10.45 a.m.- 12.15 p.m.	Case-study: GIS applications to agriculture	V. Barrena Univ. Agraria
	2-5 p.m.	<u>Student</u> project: practical exercises utilizing the entire contents of the course	United Nations/ WMO/CONIDA/ Univ. Agraria
Thursday 24 October	9 a.m.- 12.15 p.m.	<u>Student</u> project (continued)	
	2-5 p.m.	<u>Student</u> project (continued)	
Friday 25 October	9-10.30 a.m.	Discussion of the <u>student</u> project	
	10.45 a.m.- noon	Course evaluation	United Nations
	Noon- 12.30 p.m.	Closing ceremony	Co-sponsors
